

MULTIPLE COLOR STIMULUS INDUCED STEADY STATE VISUAL EVOKED POTENTIALS

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Abstract—Steady state visual evoked potentials (SSVEP) are of the characteristics of high SNR and effectiveness in short-term identification of evoked responses. In most of the SSVEP experiments, single high frequency stimuli are used. To characterize the complex rhythms in SSVEP, a new multiple color stimulus pattern is proposed in this paper. FFT and bispectrum analysis methods are used to detect the phase coupling of the two stimulation frequencies in the recorded SSVEP. The results show that the rhythms at the duplication, sum or difference of the two stimulation frequencies can be evoked by multiple color stimulus.

Keywords—steady state visual evoked potentials, multiple color, FFT, bispectrum

I. INTRODUCTION

Visual evoked potential (VEP) is the electrical response of brain under visual stimulation, which can be recorded from the scalp over the visual cortex of the brain. A distinction is made between transient VEP and steady-state VEP (SSVEP) based on the stimulation frequencies. The former arises when the stimulation frequencies are less than 2 Hz. However, if the repetition rates of stimuli are faster than 6 Hz so that the new stimuli are presented before the last response of the visual system vanishes, a periodic response called SSVEP will result. It is composed of a series of components whose frequencies are exact integer multiples of the stimulation frequency. SSVEP is usually used in the short-term identification of evoked responses because of its high SNR, such as in brain-computer interface [1].

A wide range of approaches to detect SSVEP has been devised which exploit its periodic nature. A comb filters tuned to the stimulation frequency and its harmonics has been used to estimate the SSVEP [2]. An adaptive line enhancer (ALE) was used to extract the periodic component from random background noise [3]. A new approach of adaptive filtering in which both the amplitude and phase of the SSVEP are tracked was presented in [4]. A periodogram-based method is applied successfully to detect SSVEP also [5]. Some other techniques include classical frequency-domain approach [6], adaptive matched filtering [7], time-frequency analysis [8], and subspace average [9]. These methods do not involve the correlation between each harmonic. Higher-order spectral analysis can provide more information than second-order spectral analysis in this aspect. Bispectrum is used in [10] for the detection of phase-coupled harmonics in background noise. The results obtained for SSVEP suggest that the nonlinearity of human's visual system have at least seven orders.

The stimuli used to induce SSVEP are typically flashing lights or reversing checkerboards. As only one frequency

predominates in the SSVEP, the background noise or artifacts may reduce the reliability of the detection. A new stimulation pattern was adopted in our study in which the subjects were exposed to two frequency stimuli simultaneously. The SSVEP obtained would include the two frequencies and their coupling components, which would be beneficial to improve the reliability. Characteristics and detection methods of SSVEP induced by multi-frequency stimulus, especially by multiple color stimulus, will be described in this paper.

II. METHODS

A. Multiple color stimulation

In our previous study, four blinking blocks on the monitor were placed close together and flashed at two different frequencies simultaneously as the visual stimuli [11]. Subjects were asked to focus their eyes on the center of the stimuli. The disadvantage of this method was that if the subjects shifted their eyes from the center of the stimuli during the experiments, the two frequencies would have different stimulation intensity.

In our recent study, four blinking blocks are replaced by a multiple color stimulus pattern.

The subjects were seated comfortably in a sound controlled room with dim lighting. Their eyes fixed on the screen of a computer monitor in front of them, on which the stimuli were presented.

One blinking block was shown on the monitor, but its color was subject to two different frequencies. Red and black represent the two states “On” and “Off” of first frequency, green and black represent the two states of second frequency. If both of the frequencies are in the state of “On”, the real color of the block is yellow. Fig.1 shows the multiply color, two frequency stimulus pattern.

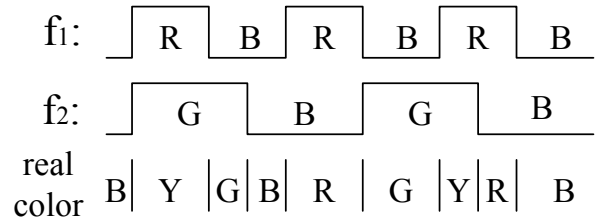


Fig.1 The multiply color, two frequency stimulus pattern. R: red, B: black, G: green, Y: yellow.

B. Signal Acquisition and Processing

The EEG signals were recorded with 200 Hz sampling rate at two monopolar channels O1 and O2 according to the

Report Documentation Page

Report Date 25 Oct 2001	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Multiple Color Stimulus Induced Steady State Visual Evoked Potentials		Contract Number
		Grant Number
		Program Element Number
Author(s)	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) Institute of Biomedical Engineering Department of Electrical Engineering Tsinghua University Beijing 100084, P.R. China		Performing Organization Report Number
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group PSC 802 Box 15 FPO AE 09499-1500		Sponsor/Monitor's Acronym(s)
		Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 3		

international 10-20 system and referred to left and right lobe respectively. A notch filter and a high-pass filter with cutoff-frequency of 2 Hz were used to reduce power-line interference and base-line shift.

As the purpose of this paper is to detect the phase coupling of the two stimulation frequencies in the recorded SSVEP, the data are processed in frequency domain using FFT and bispectrum analysis.

The bispectrum $B(w_1, w_2)$ is defined as the 2-D Fourier transform of the third-order cumulant $c_3(m, n)$. Let $\{x_k, k=0, \pm 1, \pm 2, \dots\}$ denote a discrete-time, real-valued stationary random process, then

$$c_3(m, n) = E[x_k x_{k+m} x_{k+n}] \quad (1)$$

$$B(w_1, w_2) = \sum_{m=-\infty}^{+\infty} \sum_{n=-\infty}^{+\infty} c_3(m, n) \exp[-j(w_1 m + w_2 n)] \quad (2)$$

Bispectrum is effective for the detection of nonlinearity. Suppose that there are three frequency components f_1 , f_2 and f_3 with the phases of ϕ_1 , ϕ_2 and ϕ_3 in the signal, and the relationships of $f_3 = f_1 + f_2$ and $\phi_3 = \phi_1 + \phi_2$ exist (so-called Quadratic Phase Coupling), a peak at the location (f_1, f_2) will then emerge in the bispectrum.

III. RESULTS

A. FFT method

Fig. 2 shows the result by FFT method for a SSVEP record induced by multiple color stimulus. Data length is 1024 points. The two stimulation frequencies are 6.45 Hz and 13.87 Hz. The peak components at these frequencies, the duplation (i.e. 12.89 Hz) and the difference (i.e., 7.42 Hz) are obvious in the figure, which suggests that the phase coupling of the two stimulation frequencies do exist in SSVEP signal.

B. Bispectrum analysis method

Fig. 3 shows the results by bispectrum method. The stimulus frequencies are 7.23 Hz and 8.01 Hz. Zero-phase

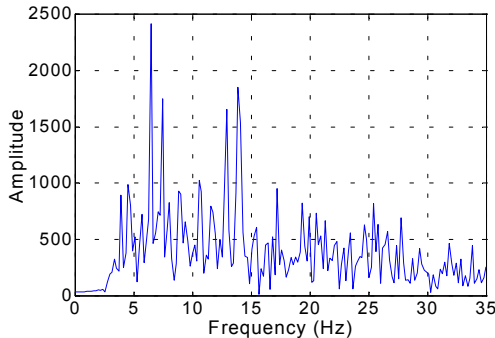


Fig. 2 Spectrum of SSVEP under multi-frequency stimulation.

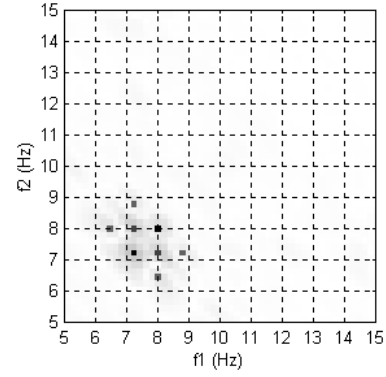


Fig. 3 Bispectrum of SSVEPs induced by 7.23 Hz and 8.01 Hz.

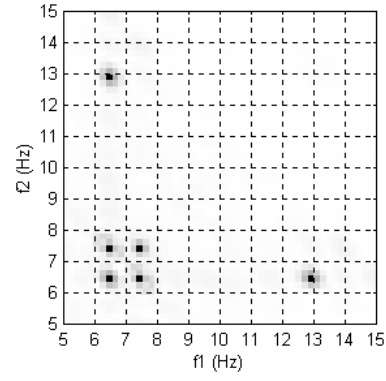


Fig. 4 Bispectrum of SSVEPs induced by 6.45 Hz and 13.87 Hz.

forward and reverse filtering is used in preprocessing to avoid phase distortion. The results are estimated via direct (FFT-based) approach.

Each data segment has 512 samples, and FFT length is 1024. The final results are the average of 40 times. We need to concentrate only on the region $0 \leq f_2 \leq f_1$ due to the symmetry properties of bispectrum. In addition to the frequencies of 7.23 Hz and 8.01 Hz, four more peaks emerge at (8.01, 6.45), (8.79, 7.23) and their symmetrical positions. Apparently, they are produced by one of the stimulation frequencies and the second harmonic of the other stimulation frequency.

The stimulation frequencies in Fig. 4 are 6.45 Hz and 13.87 Hz. Though no peak emerges at (13.87, 6.45), the peak at (7.42, 7.42) reveals the second harmonic of the difference of the two stimulation frequencies, which needs at least the fourth order non-linearity.

IV. DISCUSSION

Rhythms at the duplation, sum or difference of the two stimulation frequencies can be evoked by multiple color stimulus. As Fig. 3 and 4 have shown, this new stimulus pattern is effective to yield the coupling components of the two stimulation frequencies.

Considering that in this new stimulus method, the stimulation block has smaller size and the subjects have no

necessity to concentrate on the center of the multiple blinking blocks, it is more preferable than four blinking block method.

V. CONCLUSION

This paper presents a new approach for SSVEP induction. Multiple color stimulation was used as a new stimulation pattern to induce SSVEP. Quadratic phase coupling of the stimulus frequencies was found in the recorded SSVEP signals according to bispectrum analysis.

Further study is needed to optimize the colors used in this method so that the best stimulation effects can be achieved.

ACKNOWLEDGEMENT

This work was supported by the School of Life Science and Engineering of Tsinghua University and the National Natural Science Foundation of China under Grant No. 59937160.

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